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1 The present invention relates generally to stabilized
mounts for cameras and more particularly to a three axis, flex-
ure supported gimbal.

 When a camera is mounted and operated in a moving
5 vehicle, the camera is normally subjected to all the motions
experienced by the vehicle. A photograph of a stationary object
taken by the camera would reflect all of these motions in the
picture. The resultant effect, of course, would be blurring of
the picture due to relative motion between the camera and the
10 stationary object or scene being photographed. Aerial cameras
mounted in aircraft, for example, are often employed to photo-
graph the terrain over which the aircraft flies. For each par-
ticular picture, the film in the camera is usually moved in the
direction of flight at a rate which minimizes image motion on the
15 film due to forward motion of the aircraft. This is conventional
image motion compensation. However, blurring of the picture
may still occur because of gyrations of the aircraft mounting
the camera which introduces other, uncompensated relative
motions. Of course, there is always the effect of vibration and
20 other oscillatory motions on the camera.

 Stabilized platforms or steady mounts are provided to
isolate the camera, for example, from disturbing aircraft motions
particularly when an exposure is made. Such mounts are also
employed to rotate the camera about a pitch axis at a constant
25 rate to compensate for image motion due to the forward velocity

57-20

1 of the aircraft, when an exposure is made. These platforms or
mounts are supported on a suitable gimbal system having usually
three degrees of freedom so that a camera mounted on it can be
rotated about a pitch axis, roll axis and yaw axis. The camera
5 is moved by torquers (torque motors) which are responsive to
motion detecting means which sense motion about any of the three
axes. The conventional gimbal rings mounted on bearings intro-
duce a good deal of friction such that system response can be
spotty and faulty.

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10 It is an object of this invention to provide an extremely
low friction torque gimbal.

Another object of the invention is to provide a novel three
axis, flexure supported gimbal.

Another object of the invention is to provide a compact
15 gimbal capable of supporting heavy loads without introducing
frictional resistance.

A further object of this invention is to provide a three
axis, flexure supported gimbal having a wide range of motion
about any axis.

20 Briefly, the foregoing and other objects are preferably
accomplished by providing an upper cylindrical ring-shaped body
having two diametrically dependent side flanges which fit into an
upper channel cut diametrically across a cylindrical middle body,
each side flange being supported on a pair of crossed flexures
25 connecting with the middle body. The middle body has a lower

57-20

1 channel cut diametrically at right angles to the upper channel,
the top part of the lower channel intersecting with the bottom
part of the upper channel to form an axial center opening through
the middle body. A channel shaped lower body having an upright
5 center pillar fits in the lower channel of the middle body such that
the pillar extends upwards through the axial center opening of the
middle body. The middle body is supported on two sets of flex-
ures, each set of crossed flexures respectively connecting the
ends of the channel shaped lower body to the middle body at the
10 ends of the lower channel thereof. A center support column
structure, which is a channel shaped bar, is positioned parallel
to the upright centerpillar of the lower body and extends up through
the middle body's axial center opening and through the upper, ring-
shaped body. The center support column structure is connected
15 to the upright pillar of the lower body through two sets of crossed
flexures.

The top of the center support column structure can be
fastened to aircraft structure, for example, and a camera can be
adapted to be mounted and secured to the upper body such that the
20 intersection of the planes of the first set of crossed flexures define
a pitch axis, the second set a roll axis and the third set a yaw axis.
Each pair of crossed flexures can be thin metal strips which are
mounted near together with the planes of the flexures being per-
pendicular to each other. The flexures can be of uniform thick-
25 ness, have a tapered cross section or otherwise varied to secure
desirable or suitable characteristics.

1 This invention possesses numerous other objects and
 features, some of which together with the foregoing, will be set
 forth in the following description of a preferred embodiment of
 the invention, and the invention will be more fully understood
 5 by reference to the attached drawings, in which:

Figure 1 is a side view of a camera being supported on
 a stabilized mount of preferred construction;

Figure 2 is a rear view of the supported camera of Figure 1;

Figure 2a is a drawing illustrating a push-pull linear sole-
 10 noid;

Figure 3 is a side view of the camera stabilized mount
 structure showing torquer solenoids connected to a three axis,
 flexure supported gimbal;

Figures 3a, 3b, 3c and 3d are detail drawings of a bracket
 15 which is attached to an upper yoke of the mount;

Figure 4 is an end view of the mount;

Figures 4a and 4b are detail drawings of the upper yoke;

Figure 5 is a top plan view of the mount;

Figures 5a and 5b are detail views of an adapter plate;

Figure 6 is a bottom view of the mount;

Figures 6a and 6b are detail views of a lower yoke;

Figure 6c is an elevational view of a bracket arm;

Figure 7 is a partial sectional view which illustrates the
 connection between camera structure to airframe through the
 25 flexure gimbal;

1 **Figures 7a, 7b and 7c are detail views of a trunnion member**
which connects a cylindrical ring member supporting the camera
to the flexure gimbal;

5 **Figures 7d, 7e and 7f are detail views of the cylindrical**
ring member;

Figures 7g, 7h, 7i and 7j are detail views of a ball joint
structure;

Figure 8 is a perspective of a three axis, flexure supported
gimbal;

10 **Figure 9 is an end elevation view of the flexure gimbal;**

Figure 10 is a bottom view of the flexure gimbal;

Figure 11 is a side elevation view of the flexure gimbal;

Figure 12 is a sectional view taken along the line 12-12 in
Figure 11;

15 **Figure 13 is a top plan view of the flexure gimbal;**

Figures 14 and 15 are sectional views taken along the lines
14-14 and 15-15, respectively, in Figure 13.

Figure 16 is a front view of a captivator, looking at the
back of the camera;

20 **Figure 17 is a perspective showing the U-frame structure**
of the captivator;

Figures 17a, 17b and 17c are fragmentary, enlarged views
illustrating detail captivator structure;

Figure 18 is a back view of the captivator actuator which
25 **drives a pair of captivator sliders to cage and uncage the camera;**

1 **Figure 19 is a circuit diagram of the captivator drive motor
and clutch;**

Figure 20 is a perspective of a shock absorber pin;

**Figures 20a, 20b and 21 are detail drawings of the shock
5 absorber;**

**Figures 22 and 23 are drawings illustrating an autobalance
assembly for the camera stabilized mount;**

**Figures 23a, 23b and 23c are detail views of the autobalance
weight;**

10 **Figure 24 is a functional servo block diagram for single
axis stabilization;**

**Figure 25 is a block diagram illustrating a gyro loop used
in the camera stabilized mount;**

Figure 26 is a block diagram of the pitch axis servo channel;

15 **Figure 27 is a detailed wiring diagram of a preamplifier
used in a servo channel;**

**Figure 28 is a detailed wiring diagram of a torquer amplifier
used in a servo channel;**

**Figure 29 is a detailed wiring diagram of a half section of
20 a full wave magnetic amplifier; and**

**Figure 30 is a wiring diagram generally illustrating the
control circuitry for the camera stabilized mount.**

25

1 **Figures 1 and 2 are simplified drawings which illustrate**
a general arrangement in which a camera 10 can be mounted on
a preferred embodiment of the invention. The camera 10 is shown
only in outline form for clarity of illustration and the camera 10
3 in this instance is depicted as being mounted in an aircraft, for
example. Figure 1 is a side view of the camera mounted so that
the forward end of the aircraft is to the left, as indicated by
arrow 12 and the view shown in Figure 2 is that looking forward
from behind the camera 10. The camera 10 is a conventional
10 aerial camera for taking pictures of the terrain over which the
aircraft flies. The optics of the camera 10 are suitably arranged
to look downward at the ground which is towards the bottom of
the sheet in the illustrations of Figures 1 and 2. The camera 10
is conventional but is structurally adapted to fit on the stabilized
15 mount.

A tube 14 is mounted transversely in the aircraft between
a left wall flange 16 and a right wall flange 18. Both ends of the
tube 14 are each terminated in a pair of parallel ears 20a and 20b,
between which the flanges 16 and 18 extend and are each secured
20 thereto by bolts 22a and 22b (Figure 2). Thus, aircraft structure
is effectively extended from one wall to the other in the form of
a tube 14. This tube 14 passes transversely through the body of
the camera 10 through a tunnel formed by a larger tube 24, con-
centric with tube 14 and which is integrally a part of the camera 10.
25 The camera 10 literally surrounds the tube 14, in this instance.

1 The inner tube 14 has two dependent flanges 26 and 28
(Figure 2) which are parallel to each other and lie in planes
that intersect the wall of the inner tube 14 at right angles. Each
flange 26 or 28 is equidistantly spaced on opposite sides near
5 the middle of the length of tube 14, and have two holes in each
through which two bolts 30 can be passed parallel to the axis
of tube 14. These bolts 30 attach and secure a "ball joint"
structure 32 having flaring lower sides 32a to the inner tube 14
which is effectively aircraft structure. The larger, outer tube
10 24 has a lower central cutout 34 which permits the ball joint
structure 32 to reach the inner tube 14, and the outer tube 24
is attached and secured to a cylindrical ring member 36 by four
bolts 38 which pass through holes in tab flanges 40 of the cylin-
drical member 36. The cylindrical member 36 has two diam-
15 etrically opposed end plates 42a and 42b which are affixed to the
cylindrical member 36, and each end plate has a circular cut
therein which mounts trunnions of a cross shaped trunnion mem-
ber 44. The ends of the trunnions are welded to the end plates at
the circular cuts. This trunnion member 44 is connected through
20 a three axis, flexure supported gimbal 46 to the ball joint struc-
ture 32. Thus, the camera 10 is supported by way of outer tube
24, cylindrical member 36, trunnion member 44, flexure supported
gimbal 46, ball joint structure 32, and finally inner tube 14, which
is fixed aircraft structure.

25 The camera 10 is supported on flexures; however, a safety

1 ball joint type support is provided by the lower edge of the
cylindrical member 36 and the conically sloping side of ball
joint structure 32. In the event of flexure failure, the camera 10
is effectively supported by the lower edge of cylindrical member
5 36 resting against the lower flaring conical sides 32a of ball
joint structure 32. In normal operation, these two surfaces have
a nominal clearance of 0.020 inch, for example, and there is
no contact between adjacent surfaces, and outer tube 24 is held
concentric with the inner tube 14.

10 A three axis, flexure supported gimbal is provided on
which a camera can be mounted and be oriented in any direction.
The camera 10 can be moved about any of three axes by torquer
solenoids which are mounted between gimbal rings so that each
solenoid torques only about the axis on which it is mounted. A
15 pitch solenoid 48, roll solenoid 50, and yaw solenoid 52 are
mounted between gimbal rings generally as shown in Figures 1
and 2. The torquer solenoids are preferably two coil, linear
solenoids that can either push or pull, depending upon which
coil is energized. It is in effect two solenoids set back to back,
20 and the core of a solenoid is tapered to give a nearly linear dis-
placement characteristic. Ball bushings for linear motion are
used to support the core in order to minimize friction. Tractive
force is nearly linear over a working stroke of $\pm 1/4$ inch from
center position. Figure 2a shows the construction of a push-pull
25 solenoid. A satisfactory and preferred two coil, push-pull leakage

1 flux solenoid, type PPL-200-45, is commercially available and
 manufactured by American Solenoid Company, P. O. Box 65885,
 Los Angeles 65, California.

3 Torquing moments which can be produced by the solenoids
 in the mount, for example, are: roll--1 lb.-ft., yaw--1 lb.-ft.,
 and pitch--1 1/2 lb.-ft. This mount will isolate the camera from
 disturbing airframe rates up to 20 milliradians per second. Normal
 operating angular velocities about the three axes are: roll--0 \pm 0.3
 milliradian per second, yaw--0 \pm 0.3 milliradian per second, and
 10 pitch--8 to 16 \pm 0.3 milliradians per second. These figures apply
 to a stabilized mount including camera having a weight of approx-
 imately 550 lbs., approximately 80 pounds of which are stabilizer
 components, and moment of inertia about the three axes as follows:
 roll--10 slug ft.², yaw--10 slug ft.², and pitch--20 slug ft.².

15 The point of suspension of camera mass by the flexure gim-
 bal is located, for example, at 0.010 inch above the center of
 gravity. The camera mass as denoted here includes other major
 components of the camera stabilized mount such as a gyro assem-
 bly 54, autobalance assembly 56, and servo amplifier assembly 58
 20 together with power supply. A captivator 60 or cager device is
 a major component which does not add to the camera mass since
 it is supported purely by aircraft structure. The gyro assembly 54
 is a conventional assembly including three single axis rate gyros 62
 which are mounted mutually perpendicular to each other and sense
 25 angular motion respectively about the three axes of the camera

1 stabilized mount. Reeves hermetic integrating gyros, type HIG-5,
for example, can be satisfactorily used in this application. A
temperature controller for the gyros, gyro spin motor power
supply and gyro signal generator power supply are included in
5 the gyro assembly 54 and are also all conventional items.

An autobalance assembly 56 (Figure 1) is used to compen-
sate for change in the static balance of the camera caused by trans-
port of film from the camera supply reel onto the takeup reel. The
autobalance assembly 56 includes a long tube 64 located along the
10 length of the camera on one side, containing a movable weight
that is actuated by a system of pulleys and a d. c. motor 66. Com-
mands to shift the weight are derived from a stabilized mount servo
circuit where error signals due to static unbalance are detected.
The autobalance drive motor 66 is, for example, a 28 volt d. c.
15 permanent magnet type motor that is reversible by switching
polarity of the brushes. Limit switches are conventionally pro-
vided at both ends of the tube 64 to cut off the drive motor 66 if
a condition exists where the weight is driven to an end of the
tube 64. Manual operation can be accomplished by two auxiliary
20 switches 68 located at one end of the tube 64.

Static unbalance of the camera causes it to drift in the
direction of unbalance. Thus, a steady state error signal is
present whenever the camera becomes unbalanced. This stabil-
ization error is detected by the gyro sensors 62 and amplified
25 by a servo amplifier. The amplified signal actuates a control

1 relay which energizes the autobalance drive motor 66 to move
a slug so as to compensate for unbalance of the camera. The
weight of the slug is, for example, 3.75 lbs. and the compensa-
tion rate can be 0.67 in.-lb./sec. Compensation must take place
5 only during the steady state portions of the stabilizing cycle; as
transient rates caused by motion of the airframe at the time of
uncaging, unequal reaction of captivator pins, and switching to
image motion compensation, must not be used since they are
not caused by the static unbalance of the camera.

10 The camera stabilized mount servo generally comprises
three velocity servo channels; pitch, roll and yaw. Each channel
is substantially independent electrically of the other two and
each channel includes a rate gyro, gyro preamplifier, torquer
amplifier, power amplifier and push-pull solenoid. These
15 amplifiers are located mainly in container 70, and various elec-
trical interconnections are made in junction box 72 (Figure 1).
Two smaller containers 74 and 76 respectively contain a film
drive servo and oblique servo. These servos are all mounted
on one side of the camera 10 below the autobalance tube 64.

20 The captivator 60 or caging device includes a U-shaped
frame 78 which cradles the camera 10 between two bracketing
arms that are connected by a common cross member positioned
to the rear of the camera 10. The ends of the two bracketing
arms each terminate in the form of a yoke which embraces the
25 outer end of the inner tube 14 and are secured to the inner tube

1 by bolts 80a and 80b which pass through respective yokes and
tube 14. The corners of the U-shaped frame member are sup-
ported by adjustable airframe attachment links 82a and 82b
(Figure 2) which are arranged to provide self-aligning support
5 for the U-shaped frame member 78 in spite of slight temper-
ature expansion or contraction of the frame member, or the
like. Thus, the U-shaped frame is supported purely by air-
frame structure.

The captivator 60 also includes a 400 c. p. s. 3 phase
10 motor 84 which is used to drive a magnetic hysteresis clutch
which, in turn, drives a crank through an output shaft (all not
shown here) to operate a set of sliders 86a and 86b, uncaging
the camera 10. The sliders 86a and 86b engage with a set of
corresponding pins 88a and 88b which are mounted on shock
15 absorbers, one on each side of the camera 10. The shock ab-
sorber pins 88a and 88b are respectively engaged by the capti-
vator sliders 86a and 86b when the camera is caged. The output
shaft which drives the crank that operates the set of sliders 86a
and 86b is spring loaded through suitable gearing by a heavy coil
20 spring in tube 90. This spring drives the sliders 86a and 86b
together, caging the camera 10, whenever the magnetic clutch
is de-energized or in the event of power failure to the 3 phase
motor 84 which normally runs continuously. When the magnetic
clutch is energized, the crank is rotated against the load of the
25 heavy coil spring until a mechanical limit stop is contacted, and

1 the clutch then slips until the end of the uncage part of the cycle.

Each slider is preferably an aluminum casting that slides on nylon bushings on a pair of parallel 5/8 inch diameter steel shafts. Nylon snubbers are used on the surfaces of the slider

5 contacting pins 88a and 88b to minimize shock load and wear.

A spring loaded detent (not shown here) is also provided so that the crank, when manually turned to its extreme uncage position, can be locked in this position by pressing the spring

loaded detent in to engage an end of a half segment gear which is affixed to and drives the output shaft. The force due to the heavy coil spring transmitted through the half segment gear

10 against the detent, holds the detent in position. The captivator 60 serves to recenter the camera 10 after an exposure cycle,

for example, and it locks the camera 10 to the airframe when

15 stabilization is not in process. The captivator 60 will be further described later.

A normal sequence of operation is generally that as the aircraft flies over terrain where it is desired to photograph an area later along its flight path, film is first properly drawn in the camera 10 and it is then uncaged by energizing the magnetic hysteresis clutch which operates the crank and sliders of the captivator 60, permitting the camera 10 to rotate freely in all three axes about a point. Unless stabilized, the camera 10 would move uniformly at the same angular velocities possessed by the

25 airframe at the instant of uncaging (laws of motion), to which

1 the camera was caged. Upon uncaging, angular movement of
the camera is stopped during a stabilization interval in which
a viscous type of damping is provided to overdamp the camera 10
about each axis. Overdamping causes angular motion to cease
5 in minimum time. The camera 10 is stopped with respect to
gyro references, and the camera 10 is not influenced by aircraft
motion. During the stabilization interval, angular motion about
the roll, pitch and yaw axes cease. This is accomplished by
three velocity type servos, one for each axis as was described
10 earlier. Each servo channel includes a rate gyro which senses
angular motion about its corresponding camera axis during the
stabilization interval and during a later image motion compensa-
tion interval. The rate gyro output, after amplification, is fed
to its channel torquer solenoid which exerts torque opposing the
15 camera motion. Motion can be controlled within the resolution
of the gyro which is about 1/3 milliradian per second, for example.
By opposing angular motion with a torque proportional to angular
velocity, a viscous type of damping is achieved. Since the camera
is damped with respect to inertial space, it is not influenced by
20 movement of the airframe.

At the same time that camera motion about all three axes
is being stopped, the autobalance mechanism 56 is also put into
operation during the stabilization interval as described before.
After this interval, image motion compensation (I. M. C.) is
25 started by introducing a pitch angular movement of the camera 10

1 to compensate for the forward motion of the aircraft, while roll
 and yaw motion of the camera 10 remain stopped. During the I. M. C.
 period, the camera 10 rotates about the pitch axis at a fixed
 rate which can be set by the pilot by manually adjusting a suit-
 5 ably calibrated potentiometer, for example, to introduce a rate
 command signal into the pitch servo channel. A pitch compensating
 angular motion of the camera 10 results since a velocity type servo
 can command any angular velocity, as well as zero rate. During
 the I. M. C. period, while the image of the area to be photographed
 10 is motionless, the camera shutter is operated by a pulse appearing
 during this interval. After shutter operation, the camera 10 can
 be captured and securely locked to the airframe again by de-ener-
 gizing the magnetic clutch of the captivator 60. Power is also
 disconnected from the camera stabilized mount servo until the
 15 next cycle of operation. This completes a general description of
 a preferred embodiment and application of the invention.

The camera stabilized mount is shown in structural detail
 principally by Figures 3, 4, 5, 6 and 7. Additional supporting
 details of these figures are provided by Figures 3a, 3b, 3c, 3d,
 20 4a, 4b, 5a, 5b, 6a, 6b, 6c, 7a, 7b, 7c, 7d, 7e, 7f, 7g, 7h, 7i
 and 7j. The three axis, flexure supported gimbal 46 is illustrated
 in detail by Figures 8, 9, 10, 11, 12, 13, 14 and 15. The pivot
 point for the mount is indicated in Figures 3, 4, 5 and 6 by a
 small circle having alternately shaded quadrants and is at the
 25 center of this circle. Figure 3 is a detailed side view of the

1 camera stabilized mount which shows at the top a channel shaped
adapter plate 92 having two parallel upright walls 92a. A side
view of this adapter plate 92 can be seen in Figure 4 which shows
the walls 92a being curved to conform with the surface of inner
5 tube 14 and two holes 92b in each upright wall 92a near the ends
are provided to accept the two bolts 30 which secure the adapter
plate 92 to the flanges 26 and 28 of the inner tube 14 (see Figure
2). The adapter plate 92 is detailed in Figures 5a and 5b, and
is shown properly installed in Figure 5. The adapter plate 92
10 rests on the upper peripheral surfaces of ball joint structure 32
which, in turn, stands on the top edges of the upper yoke of flexure
supported gimbal 46 as shown in the partially sectional view of
Figure 7. The ball joint structure 32 is shown in detail by Fig-
ures 7g, 7h, 7i and 7j. Four holes 94 forming a square are pro-
15 vided through this structure 32 and these holes 94 are arranged
to coincide with four holes 96 in adapter plate 92 as shown in
Figure 5a. These holes 94 and 96, in turn, are aligned with
four threaded holes 98 located in the top edges of an upper body
100 of the flexure supported gimbal 46 (see the perspective of
20 Figure 8). Four long bolts 102 (Figure 5) are used to secure
the adapter plate 92 and ball joint structure 32 to the upper body 100.

The upper body 100 is supported and connected through two
sets of pitch axis flexures 104 to a middle body 106 of the gimbal
46 and the middle body 106 is, in turn, supported and connected
25 by two sets of roll axis flexures 108 to a lower body 110. The

1 lower body 110 has a raised center core section which is connected
to a center support column structure through two sets of yaw axis
flexures that hold the center support column structure parallel
with the lower body core section. Each set of flexures comprises
5 two thin metal strips mounted side by side and crossed so that the
planes of the two strips would intersect at 90 degrees if the strips
were widened and extended into each other. A strip is terminated
in cubes at each end which can be integral with the metal strip.
The strips can be other than metal, of course, and do not have to
10 be integral with the end cubes, but can be suitably secured to them.
This forms a pivot with negligible friction and a very small amount
of spring compliance. The pitch and roll axis flexures are .016
inch thick, 7/16 inch wide and 1/2 inch long. The yaw axis flexures
are the same width and length but have a tapering lengthwise cross
15 section of .014 inch minimum thickness. The lengthwise cross
sectional edges are elliptical and are .060 inch thick where they
join with the end cubes. The top of the center support column
structure has three threaded holes, triangularly spaced to coin-
cide with three holes 112 bored in the center of the trunnion mem-
20 ber 44 as shown in Figure 7b. Figures 7a, 7b and 7c fully illus-
trate the trunnion member 44. The ball joint structure 32 has
three larger holes 114 (Figure 7i), triangularly spaced, to per-
mit passage and installation of three bolts 116 (Figure 5) which
secure the trunnion member 44 to the center support column
25 structure as shown in Figure 7.

1 The cylindrical ring member 36 to which the end plates
42a and 42b (Figures 3 and 4) are affixed, is shown in detail by
Figures 7d, 7e and 7f. Since the end plates 42a and 42b are
respectively welded to the ends of the two trunnions of the
5 trunnion member 44, and the cylindrical ring member 36 is
fastened by bolts 38 (Figure 2) through tab flanges 40 to the
outer tube 24, which is integral with the camera 10, the camera
10 is thus supported on the three axis, flexure supported gim-
bal 46 and a safety ball joint type support is provided by the
10 lower inner edge of cylindrical ring member 36 and the flaring
conical lower side of ball joint structure 32 (Figure 7).

The brackets that support the torquer solenoids are
mounted between gimbal rings so that each solenoid torques
only about the axis on which it is mounted. The pitch solenoid 48
15 is fastened dependently to a bracket 116 which is, in turn, secured
to an upper yoke 120. The upper yoke 120 is illustrated in detail
by Figures 4a and 4b and is attached to the middle body 106 by
cap screws 120a as shown in Figures 3, 4 and 6. The pitch
solenoid 48 is connected to an upper bracket arm 122 through
20 a circular flexure 124. The upper bracket arm 122 is fastened
to a lower side area 126 (Figures 7h and 7j) of structure 32 by
screws 126a as shown in Figures 3 and 4. A differential trans-
former 128 is attached to bracket 116 and is connected to the
upper bracket arm 122 by circular flexure 128a. This instrument
25 128 is provided so that indication of angular displacement of the

1 camera 10 about the pitch axis can be obtained.

A bracket 130 which is detailed in Figures 3a and 3b is also attached to the upper yoke 120. Another bracket 131 detailed in Figures 3c and 3d is located below bracket 130 and is
5 attached to the lower yoke 132. The lower yoke 132 is secured to the lower body 110 by cap screws 132a, and is shown in detail by Figures 6a and 6b. The roll solenoid 50 is secured independently from bracket 130 and is connected to bracket 130 through a circular flexure 134. Thus, roll solenoid 50 is con-
10 nected between the lower body 110 and middle body 106. The yaw solenoid 52 is mounted laterally to bracket 130 which is also fastened to the lower yoke 132 as is clearly shown in Figures 4, 5 and 6. The yaw solenoid 52 is connected by a circular flexure 138 to a bracket arm 140 which is attached to the bottom
15 of the center support column member 142 (Figure 6). An elevational view of the bracket arm 140 is illustrated in Figure 6c. Thus, the yaw solenoid 52 is connected between the lower body 110 and the center support column member 142 which is secured to the trunnion member 44 that effectively supports the camera 10.

20 To show clearly how the solenoids are connected between gimbal rings, reference can be made to Figures 8, 9, 10, 11, 12, 13, 14 and 15 which are detailed drawings of the flexure supported gimbal 46. The perspective of Figure 1 illustrates the general appearance of a preferred embodiment of a three axis, flexure
25 supported gimbal. The three axis gimbal 46 comprises four main

1 parts--an upper body 100, middle body 106, lower body 110 and
 a center support column member 142. The upper body 100 is a
 cylindrical ring-shaped structure having a large diametrical,
 circular cut 144 intersecting the side walls of the structure 100
 5 partially below the top surface over two dependent side flanges
 146a and 146b. This cut 144 provides clearance for the trunnions
 of the trunnion member 44. The four threaded holes 98 located
 around the top edges of the upper body 100 thread with bolts 102
 (Figure 5) which secure the upper body 100 to ball joint structure
 10 32 (and aircraft structure).

Two sets of countersunk holes 148a and 148b are also pro-
 vided through the side flanges 146a and 146b as shown in Figures
 11 and 13. These holes 148a and 148b accept screws 150a and 150b
 which thread into the upper cubical ends of the pitch axis flexures
 15 104. These upper cubical ends are held by the screws 150a and
 150b in the corners of the M shaped (Figure 11) lower edges of
 the side flanges 146a and 146b. Similarly, two other sets of holes
 154a and 154b are drilled axially through the upper body 100 along
 the rim 90 degrees away from the holes 148a and 148b. These
 20 holes 154a and 154b provide through passage of screws 156a and
 156b (Figures 9 and 14) which thread diagonally into the upper
 cubical ends 158a and 158b of the roll axis flexures 108. The
 upper body 100 has a large central opening 160 formed by boring
 parallel to the sides of the cylindrical upper body 100 partway
 25 down (Figures 14 and 15), spherically recessing the bottom and

1 then reaming a rounded corner, square hole 162 (Figure 13)
 through the recessed area. This provides clearance for the
 raised core section of the lower body 110 and the center support
 column member 142.

5 The middle body 106 is also generally cylindrical conform-
 ing (for cooperation) with that of the upper body 100. The middle
 body 106 is essentially a solid round cylinder having an upper
 channel 164 cut through the cylinder from the top surface and
 about halfway down the side, the bottom of the channel 164 form-
 10 ing a W shaped edge (Figure 11). A lower channel 166 is similarly
 cut through the middle cylinder, the height of the channel 166 being
 from the bottom surface of the cylinder running up approximately
 halfway to the top, the channel 166 ending in a M shaped groove
 (Figure 9). The lower channel 166 is oriented at right angles
 15 to the upper channel 164.

Countersunk holes in middle body 106 aligned with holes
 154a and 154b accept the screws 156a and 156b (Figures 9 and 14)
 which thread into the upper cubical ends of the roll axis flexures
 108, the cubical ends fitting into the corners of the top of the M
 20 shaped channel 166. Similarly, two pairs of countersunk holes
 170a and 170b (Figures 10 and 15) accept screw pairs 172a and
 172b, respectively, which thread into the lower cubical ends of
 the pitch axis flexures 104. The lower cubical ends of these
 flexures 104 are held down in the corners of the W shaped groove
 25 of the upper channel 164. Thus, the pitch axis flexures 104

1 connect the upper body 100 to the middle body 106 in an axis
parallel to the upper channel 164.

The middle body 106 has two notched, flat areas 152a
and 152b and a flat area 156 (Figures 9, 11 and 12). The areas
5 152a, 152b and 156 can be milled flat for the length of the middle
body cylinder as shown in Figure 11, for example. Threaded
holes 176a, 176b and 178 are provided so that the formed ends
and middle of upper yoke 120 can be fastened to the middle body
106 by cap screws 120a (Figures 3 and 4).

10 The lower body 110 is generally a cross channel bar 180
(Figure 10) having an upper W shaped surface (Figure 9) and an
upright center core 182 perpendicular to the bar as shown in
Figures 12 and 14. The channel bar 180 has a cutout area 180a
(Figure 10), the inner profile of the cut 180a having a joggled
15 W cross sectional edge identical to the inner surface of the
upright center core 182, which is a direct pillar extension from
the channel bar 180 (see Figure 12). The lower body 110 also
has two flat areas 184a and 184b in which are located two pairs
of threaded holes 186a and 186b, the latter pair not visible (Fig-
20 ures 9, 10 and 11). The ends of lower yoke 132 are fastened to
these holes 186a and 186b by the screws 132a as was shown in
Figures 4 and 6.

Two pairs of countersunk holes 188a and 188b are drilled
in the bottom of the channel bar 180 near the two ends to receive
25 screws 190a and 190b which thread into the lower cubical ends

1 of the roll axis flexures 108 (Figures 9 and 10). Thus, a roll
axis parallel to the axis of the channel bar 140 is defined by
the line of intersection of adjacent planes of the roll flexures 108.
Two pairs of countersunk holes 192a and 192b are also drilled
5 through the upright center core 182 of the lower body 110 as
shown in Figures 12 and 15. Since Figure 12 shows only the
lower pair of yaw flexures, Figure 14 can be additionally re-
ferred to for exact location of the threaded holes 192a. Screw
pairs 194a and 194b respectively fasten the upper and lower cub-
10 ical ends of the yaw axis flexures 196 to the upright center core 182.

The center support column member 142 is a channel bar
which has a W shaped inner cross sectional edge in which the ends
of the W are bent inwards, as can be seen in Figures 12 and 13.
Two pairs of countersunk holes 198a and 198b are drilled through
15 the center support column member 142 as shown in Figures 12 and
15. As before, Figure 14 can be used to determine the exact
location of holes 198a. Similarly, two pairs of screws 200a and
200b thread into the upper and lower cubical ends of the yaw axis
flexures 196 through holes 198a and 198b, respectively. The yaw
20 axis flexures 196 thus connect (and support) the center support
column member 142 to the lower body 110. Four of five threaded
holes 202 tapped in the bottom of the center support column mem-
ber 142 (Figures 10 and 11) accept cap screws 204 (Figure 6) which
secure the bracket arm 140 to the center support column member
25 142. The three threaded holes 206 (Figure 13) in the top of the

1 center support column member 142 receive the three bolts
 116 which secure the trunnion member 44 to it. Thus, a yaw
 axis which is normally parallel to the axis of the center support
 column member 142 is defined by the intersection of the planes
 5 of the crossed yaw axis flexures 196a and 196b.

The captivator 60 is shown in greater detail in Figures
 16, 17, 17a, 17b and 17c. Figure 16 is a front view of the cap-
 tivator 60 (in back of camera 10) showing the mounting of 3 phase
 motor 84 with a housing 208 which contains a magnetic clutch
 10 and suitable gearing to drive the output shaft connected to oper-
 ate the captivator sliders 86a and 86b. Tube 90 houses a heavy
 coil spring 210 which is shown in a disconnected condition in
 Figure 18.

The heavy coil spring 210 is normally somewhat compressed
 15 when cable 212 is connected to end plug 214. The 3 phase motor 84
 drives a magnetic hysteresis clutch 214 through a 5 to 1 spur gear
 reduction 216. Pinion 218 keyed to the output shaft of clutch 214
 drives an output shaft 220 through conventional 141 to 1 reduction
 gearing 222. The reduction gearing 222 drives a half segment
 20 gear 224 which is mounted and affixed to the output shaft 220, as
 shown. Reduction gearing 222 includes a bevel gear 220a which
 meshes with the pinion 218, a small diameter spur gear which is
 mounted and secured to the same (bearing supported) shaft 220b
 as the bevel gear 220a (not visible under bevel gear 220a) meshes
 25 with a larger diameter spur gear 220c on another bearing supported

1 shaft 220d. Another small diameter spur gear 220e is affixed
to the latter bearing supported shaft 220d and meshes with
another larger diameter gear 220f mounted and secured to a
large, bearing supported shaft 220g which also mounts (under-
5 neath) a small diameter spur gear that meshes with the half
segment gear 224. The cable 212 is fastened to the output
shaft 220 and can be wound up around the shaft 220 as the shaft
220 is rotated by the gearing 222 driving the half segment gear
224. This, of course, further compresses the heavy coil spring 210.

10 The half segment gear 224 is shown in Figure 16 with one
end (which can be engaged by the spring loaded detent) braced
against an end of a mechanical limit stop 226 which is a rectan-
gular shaped nylon block. The other end of the half segment gear
224 engages with the other end of the rectangular limit stop 226
15 when driven to this position by clutch 214 and gearing 222. The
clutch 214 slips in this condition as stated before. A spring
loaded detent 228 (Figure 16) is positioned near the output shaft
220, the end of which can be manually turned by a suitable wrench.
A selenium rectifier 230 (Figure 18) derives 50 volts d. c. from a
20 115 volts a. c. supply for energizing the clutch 214. The circuit is
shown in Figure 19 wherein the 115 volts a. c. is provided only
during the uncage period. A filter capacitor 232 is connected across
the supply lines after the rectifier 230. To slow the release of the
clutch 214, it is shunted with a capacitor 234 in series with a re-
25 sistor 236. Without this feature, the capacitor sliders 86a and 86b

1 would be driven closed very rapidly by the heavy coil spring 210
thereby introducing undesirable transient vibrations in the cam-
era 10.

Figure 17 is a perspective which illustrates the general
5 construction of the captivator. The U-shaped frame 78 is clearly
portrayed and it can be seen that the common cross member 238
connecting the bracketing side arms 240 and 240b mounts a
double acting crank 242 which actuates sliders 86a and 86b. The
crank and sliders are shown in detail by figures 17a, 17b and 17c
10 which are enlarged, fragmentary views of the captivator structure.
Slider 86a is shown in Figure 17a, and slider 86b is identical to it.
The slider 86a slides on the parallel shafts 244, the ends of
which are secured to the outer ends of the connecting brackets
246a and 246b. The end brackets 246a and 246b are bolted to the
15 cross member 238 by bolts secured by nut 248. Clearance be-
tween the skin of cross member 238 and the slider 86a riding on
shafts 244 is provided by suitable thickness of the end brackets
246a and 246b. The slider 86a is a closed yoke having a base
rod 250 which can slide back and forth through a hole in end
20 bracket 246a mounting a nylon bushing 251. The other end
bracket 246b mounts a nylon pod 252 for cushioning the top of
the slider 86a. Nylon snubbers 254 are provided on the inside
edges at the top of the yoke 86a.

The end of rod 250 is pin jointed to a connecting rod 256,
25 the pin 258 passing perpendicularly through the in-line axes of

1 rods 250 and 256 and is perpendicular to the plane of the web of
 cross member 238. The connecting rod 250 can rotate about
 pin 258 over a wide angular spread. The connecting rod 256
 is connected to the crank 242 as shown in Figure 17b. The
 5 crank 242 comprises the output shaft 220 on a crankshaft which
 is keyed to rotate a double ended crankarm 260. The two ends
 are respectively connected to ends of rocker arms 262a and 262b
 through pins 264a and 264b which are mounted in bearings 266 as
 shown in Figure 17c. It can be seen in Figure 17c that the crank-
 10 arm 260 is deeply channeled at both ends to receive the ends of
 the hook shaped rocker arms 262a and 262b. The other ends of
 the rocker arms 262a and 262b have holes drilled in them in line
 with the axis of rod 250 and the end of connecting rod 256, for
 example, is inserted into the hole in rocker arm 262b and secured
 15 in place by pin 268b (pin 268a is similarly used with rocker arm
 262a). Thus, as the crankarm 260 is rotated clockwise, the rocker
 arms 262a and 262b pivot respectively with their connecting rods
 about their pivot points as, for example, at pin 258 where the con-
 necting rod 256 rotatably connects with the base rod 250 of slider
 20 86a. After the crankarm 260 is rotated 90 degrees and passes
 top dead center, the lateral translatory motion is, of course,
 transmitted to the sliders 86a and 86b, moving them outwards.
 This motion releases the shock absorber pins 88a and 88b which
 are mounted on each side of camera 10 (Figures 2 and 16), uncaging
 25 the camera 10.

1 The assembly including absorber
 shown in Figure 1 is enlarged in Figure
 5 a perspective of the shock absorber. An acc-
 of the shock absorber in true proportion
 20a, 20b and 21. The shock absorbers
 would otherwise result from impact of the
 contacting the pins 88a and 88b on cage
 Each shock absorber includes a shock ab-
 20a, swivel mounted in a housing 270 of
 10 (Figure 21) carried by the housing 270.
 degree base cone at the inner end which
 of a spring loaded plunger 274. The plun-
 ward by a spring 276 encircling the ster-
 inside a cylindrical retainer housing 278
 15 the left end of housing 270. The spring
 centers the pin 88a after release from ex-
 damping being provided by mechanical fric-
 and plunger 274 ends. A pliable O-ring
 channeled groove on the inside end of pin
 20 pin 88a at maximum deflection when con-
 side of the housing 270. The cushioning
 absorbers can be varied by adjusting the
 the plunger 274. This can be done by se-
 in or out to increase or decrease the sp-
 25 plunger 274. Spring pressure should be

on mounted as
 tion is a per-
 representation
 ovided by Figures
 to the shock that
 20a and 86b
 the camera 10.
 over pin, such as
 272
 pin 88a has a 15
 engaged by an end
 274 is urged for-
 the plunger 274
 which is threaded into
 led plunger 274 re-
 tion of the pin 88a;
 tion between the pin 88a
 he carried in a
 and cushions the
 is made with the
 of the shock
 ring pressure against
 the retainer 278
 276 pressure on the
 ecreased if the recenter-

-29-

through the channeled slots by way of slant holes 306a, 306b and 308a, 308b. The weight 284 rolls on the roller bearings 304 and is aligned and guided by the small hole 286.

A tension spring 310 housed in hole 2 is hooked on one end to a pin in hole 296 and the other spring end is tied to line 312, which passes over pulley 314 (Figure 23), looped around the pulley output shaft of d. c. motor 66 and then looped over pulley 316. The line 312 is next threaded through hole 298, continues down the length of tube 64 and then looped around a right end pulley 318 and brought back to weight 284 and tied to a pin in hole 298 as shown in Figure 22. A closed, tensioned loop is formed for moving the weight 284 back and forth in autobalance tube 64 according to the direction of rotation of motor 66. Limit switches 320a and 320b, actuated by weight 284, are provided at both ends of tube 64 to cut off motor 66. Manual operation can be accomplished through two auxiliary switches 68 at the right end of tube 64.

A functional block diagram of a preferred servo for single axis stabilization is shown in Figure 24. The diagram is applicable to any of the three servo channels controlling angular motion about the roll, pitch or yaw axes of the carrier stabilized mount. Gyro signal E_g proportional to \dot{W} , the angular velocity sensed by the gyro about the axis controlled, is mixed with $E_{\dot{C}}$, a voltage analogue of a desired angular rate (which is zero except for the pitch axis during the I. M. C. interval), and mixed output signal

1 is obtained and amplified by an amplifier b
 applied to a solenoid producing torque at th
 ratio K_t of the solenoid. The motion of the
 is referenced to the air frame, and yields
 5 according to camera compliance K_c . The
 torque T_s combined with the spring bac to
 opposed by solenoid torque T_g . If I_c is
 e-ity W about the axis controller is zero,
 ulus, solenoid torque T_g exceeds the oppo
 10 a constant angular velocity W about the cor

The single axis rate gyros 6 which
 for the camera 10 are conventional devices
 a gimbal mounting an electrically driven g
 perpendicularly to the plane of the gimbal ring
 15 and a signal generator, all hermetically se
 pletely filled with a viscous fluid. The gin
 diametrically opposing end shafts which
 perpendicular to the spin axis of the gyros
 matures of the torque generator and the
 20 spectively each mounted on an opposing
 ng. For rate gyro application with H-3-1
 the signal generator output is amplified ext
 amplified signal is used to drive the torque
 manner, the torque developed by the torque
 25 tional to the angular displacement of the gi

1 A preferred gyro loop block diagram is shown in Figure 25.

When the gyro senses angular motion, a precession torque is produced about the output axis which causes angular displacement of the signal generator armature off null position to produce an output signal. This output signal is coupled by electrostatically shielded isolation transformer T_1 to a high gain a. c. preamplifier A_1 and the amplified signal is demodulated by a demodulator which is a transistor chopper producing synchronous rectification of the preamplifier A_1 output. The demodulated signal is amplified by d. c. amplifier A_2 comprising direct coupled push-pull class B emitter followers, and applied to the control field of the torque generator. The torque generator pattern field is operated at a known current (7 ma.), and since the torque output of the torque generator is proportional to the product of the pattern field and control field currents, the applied control field current is proportional to the rate input to the gyro. The resulting torque produced by the torque generator is such to bring the gyro and signal generator armature back into null. The angular displacement of the signal generator is kept very low because of the high loop gain in the system.

Since the d. c. resistance of the torque generator is accurately known, the voltage across the torque generator (control field) is sampled for the rate output of the sensing gyro. The current in the torque generator provides an accurate measure of the angular rate if the loop gain is kept high. The rate output

1 signal is suitably applied to a torquer solenoid to drive the camera
in such a direction to oppose any motion sensed by the gyro. The
block diagram depicted circuit of Figure 26 (for the pitch channel)
illustrates a preferred manner in which this is done. The con-
5 ventional gyro 62 is represented diagrammatically. The servo
loop as shown in Figure 25 can be seen in Figure 26 and includes
pitch gyro amplifier 322, and part of torquer amplifier 324. The
output signal from the pitch gyro amplifier 322 is passed through
a conventional balanced parallel-T, low pass filter 326 to modu-
10 lator 328. An I. M. C. command can be provided to another
modulator 330 as indicated. The command is simply in the form
of a d. c. voltage which is derived off a manually adjustable and
calibrated potentiometer connected across 90 volts d. c., for
example. The modulated outputs of modulator 328 and 330, which
15 are conventional chopper modulators, are added and applied to
preamplifier 332 through a gain control potentiometer 334. The
preamplifier 332 drives two magnetic amplifiers 336a and 336b and the
magnetic amplifiers 336a and 336b each feeds one winding of the pitch
control solenoid 48. These two windings oppose each other and if an
20 equal current flows in both windings there is no force from the
solenoid. The magnetic amplifiers 336a and 336b are conventional
and of the half wave reset type. Due to the reset type of action,
these magnetic amplifiers 336a and 336b are phase sensitive and act
as their own demodulators. The phasing of the preamplifier 332
25 output to the magnetic amplifiers 336a and 336b is such that one

1 will operate on one phase and the other on the opposite phase.
Thus, one magnetic amplifier 336a drives the 'push' coil and
the other 336b drives the 'pull' coil of the solenoid 48. The
solenoid 48 drives the camera 10 in such a direction as to
5 oppose any motion sensed by the gyro 62.

The roll and yaw channels are similar except that the
I. M. C. command signal is zero and, consequently, demodulator
330 can be omitted. In the pitch channel, image motion compen-
sation is accomplished by feeding an I. M. C. voltage into chopper
10 modulator 330 and adding this to the output of the stabilizing
chopper modulator 328. The solenoid 48 will then drive the
camera 10 until the gyro 62 output is equal and opposite to the
command, at which time there will be no signal to the preampli-
fier 332. Thus, instead of nulling to zero rate, the system will
15 null to a rate which produces a voltage equal and opposite to the
command voltage. This means that when the system is nulled,
the camera 10 will be moving at a given I. M. C. rate about the
pitch axis.

The preamplifier A_1 connecting with isolation transformer T_1
20 is identical in detail circuitry to preamplifier 332, and their cir-
cuitry is shown in Figure 27. The torquer amplifier 324 is de-
tailed in Figure 28 and one of the magnetic amplifiers 336a and
336b is shown in Figure 29. These circuits are generally conven-
tional and will be briefly described. The preamplifiers each com-
25 prises an input stage which is a transistorized equivalent of a

1 cathode follower and includes a capacitor C₁ used to suppress
 parasitic high frequency oscillations. Resistor R₃ and capacitor
 C₁₂ forms a decoupling network which also provides additional
 power supply filtering. Resistors R₄ and R₅ form a bleeder network
 5 which provides bias for the first transistor Q₁. Capacitor C₂ is a
 coupling capacitor and capacitor C₂ couples the a.c. signal from
 the emitter to the bias network center which feeds the base of Q₁.
 By keeping the center of the bias network at the same a.c. potential
 as the emitter, the a.c. impedance of resistor R₁ is effectively
 10 increased by a factor of approximately 10. This is used to keep
 a high input impedance to the first transistor Q₁ which prevents
 the amplifier from loading the signal source.

The second stage of the preamplifier is a common emitter
 amplifier Q₂ which is directly coupled to the emitter of transistor
 15 Q₁. Resistor R₇ in the emitter circuit of Q₂ provides some a.c.
 gain stability. This unbypassed resistor provides negative current
 feedback in the Q₂ stage. Resistor R₈ provides negative current
 feedback at the d.c. level, and since it is 10 times as large as R₇,
 it reduces the d.c. gain of the stage to approximately 3, for
 20 example. This resistor R₈ also determines the d.c. operating
 point for transistor Q₂. Capacitor C₅ bypasses this resistor R₈
 in order to obtain a high a.c. gain for the stage. Resistor R₁₇ is
 the collector load resistor for the stage and capacitor C₁₀ is used
 to cut off the higher frequencies which would only add to noise in
 25 the system.

Capacitor C9 is a coupling capacitor to the third stage, which is also a common emitter amplifier. Resistors R16 and R18 form a bleeder bias network for transistor Q3, and resistor R9 is used to increase input resistance and stability. Resistor R10 provides d. c. temperature stability, and capacitor C6 bypasses a. c. signals. Resistor R11 is the collector load resistor for this stage and capacitor C7 is the coupling capacitor to the next stage, which is a common emitter amplifier. This stage is the driver for a push-pull output. Resistors R12, R13, R14 and R15 perform the same functions as similar resistors in the preceding stage. The gain can be varied by increasing the a. c. impedance in the emitter circuit of transistor Q4. The collector circuit of Q4 includes the primary of a driver transformer T10 which is resonated by capacitor C11 to carrier frequency. Resistor R19 loads the resonant circuit reducing its Q to broaden the resonance. This improves waveform considerably when the amplifier is overdriven and prevents strong spikes from occurring.

The output stage is a push-pull class B amplifier including transistors Q5 and Q6. The use of a class B stage reduces dissipation in the transistors when full output is not required. Resistors R22 and R16 form a bias network for the stage. This places a small forward bias on Q5 and Q6 to eliminate crossover distortion and thus prevents a small dead spot from occurring at

1 null. Resistors R20 and R21 provide bias stability and some
degeneration. The output of Q5 and Q6 is powered from a
separate collector supply identified +30 V. and +30 V. return
in order to secure good decoupling.

5 The torquer amplifier 324 is shown in detail in Figure 28,
and includes a transistor chopper (Q1', Q2', Q3', and Q4') which
is used as a demodulator, a push-pull emitter follower circuit
(Q13, Q14, Q15 and Q16) for driving the torquer (torque gen-
erator) of the gyro 62, and a modulator transistor chopper (Q5',
10 Q6', Q7 and Q8) after filtering by filter 326. An additional
modulator transistor chopper (Q9, Q10, Q11 and Q12) for con-
verting I. M. C. d. c. voltage to 400 c. p. s. is also provided for
the pitch channel. The output of the I. M. C. modulator 330 is
added to the torque generator modulator 328 by means of a
15 resistive adding network (R7' and R8') and fed to preamplifier
332. Output 1' (terminals 11 and 12) is used for the pitch channel
and output 2' (terminals 10 and 11) is used in the other two chan-
nels. Thus, transistors Q9, Q10, Q11 and Q12, capacitor C5'
and resistors R7' and R8' can be omitted from the torquer
20 amplifiers for the roll and yaw channels.

Transistors Q1' and Q2', P-N-P types, for example, are
connected back to back and comprise a single pole, single throw
switch. When the coil end having a dot is negative relative to
the other end, the transistors Q1' and Q2' are forward biased
25 and the switch is closed. When the a. c. switching voltage is

1 reversed, both transistors Q1' and Q2' are back biased and no
current flows. The transistors are used in inverted connection--the
normal collector junction is used as the emitter and the normal emitter
junction is used as a collector. In normal operation the transistors
5 are driven from cutoff to saturation, requiring little driving voltage,
to produce substantially square wave switching. Two of these single
pole throw switches are combined with a common driver transformer
to make a complete SPDT chopper. The a. c. input is converted into
a double ended, polarity reversible d. c. signal which reverses in
10 polarity with the phase of the incoming signal. This signal is alter-
nately connected to filter capacitor C1' and the bases of emitter
follower Q13 and Q14 then to filter capacitor C2' and the bases of
emitter follower Q15 and Q16. Each emitter follower uses two
transistors in parallel to provide increased power output.

15 The two emitter followers feed the torque generator
control field of gyro 62, and are connected in a bridge circuit
in which the control field of the torque generator is connected
between the emitters of the two emitter followers. The SPDT
chopper acts as a synchronous rectifier. For one phase of input
20 a. c. signal, the rectified output across the capacitor C1' and
C2' will be positive on one capacitor and negative on the other
with respect to the +30 V. line. The emitter follower with the
negative signal will follow the input and the emitter follower with
the positive signal will be cut off and its emitter will remain at
25 zero, measured with respect to the +30 V. line.

1 The stabilisation chopper comprising transistors Q5',
 Q6', Q7 and Q8 samples the voltage across the torque generator
 control field through filter 326. The chopper has two "contacts"
 connected to each side of the control field through filter 326,
 5 and an "arm" connected through a coupling capacitor C4' to
 preamplifier 332. Thus, a d.c. or low frequency a.c. input
 is converted to a modulated 400 c.p.s. output, for example.
 This modulated output reverses phase as the polarity across
 the control field of the torque generator reverses. In the case
 10 of the pitch channel, a similar additional chopper comprising
 transistors Q9, Q10, Q11 and Q12 converts a d.c. I.M.C. voltage
 into a 400 c.p.s. a.c. voltage. This signal is combined with
 the a.c. signal from capacitor C4' through a resistance adding
 network comprising resistors R7' and R8'. When these two a.c.
 15 voltages are equal and opposite, they cancel and no output signal
 is fed to the preamplifier 332 in the pitch channel. The system
 will seek a null where these two signals cancel and can only do
 this by moving the camera 10 at such a rate that the gyro 62
 output as measured across its torque generator control field
 20 equals the I.M.C. command voltage. Thus, a constant d.c. input
 to the I.M.C. chopper will command a constant rate on the camera 10.

 The output of preamplifier 332 is applied to a pair of mag-
 netic amplifiers 336a and 336b, for example, through transformer
 T3 as shown in Figure 30. A magnetic amplifier is illustrated in
 25 detail in Figure 29. Two units are used in each channel and the

1 upper end of the secondary of transformer is connected to
 input terminal 1 of magnetic amplifier 336a and to input terminal
 15 of magnetic amplifier 336b while the low end of the secondary
 is connected to input terminal 15 of magnetic amplifier 336a and
 5 to input terminal 1 of magnetic amplifier 336b. This inter-
 changing of input to a magnetic amplifier with respect to the
 other permits one to conduct for one phase of the input signal
 and the other to conduct for the other phase of the signal. One
 magnetic amplifier is connected to the "push" coil of the solenoid
 10 48 and the other to the "pull" coil. Thus, the direction of force
 is dependent upon the phase of the input signal. The magnetic
 amplifiers used are full wave devices obtained by using two half
 wave sections and feeding them from the center tapped preamplifier
 output transformer T3. The control cycle of one half wave
 15 section occurs during the load cycle of the other, and vice versa.
 If, during the control half cycle, the transistors Q1a and Q2a are
 held out off by the phase of their input signal being opposite,
 with respect to line, neither half wave section of a magnetic
 amplifier conducts and no output is obtained. The notation $\phi 1$
 20 and $\phi 2$ after the line 13 V. and 26 V. legend refer to upper and
 lower halves of a center tap grounded supply transformer coil and
 do not mean a two phase supply.

The general operation of the camera stabilized mount can
 now be described with reference to Figure 10. During a cycle of
 25 operation, the programmer 338--which is a stepping switch--makes,

1 for example, 11 steps as indicated. Film can be drawn in the
 camera 10 during the first three steps and then during the next
 three steps the autobalance relay K3 is energized together with
 the uncaging relay K2. A relay K1 is connected across the
 5 pitch solenoid 48 coils as shown and is a double pole, center
 balanced two position relay. When K2 is energized, the
 magnetic amplifier preamplifiers are energized by completion
 of the circuit of the +30 V. return line. At the same time, the
 captivator clutch 214 is energized by rectified 115 V. a.c. power.
 10 The uncaged camera 10 will be stabilized and if a static unbal-
 ance drift caused by uneven transport of film is sensed in the
 pitch channel, the poles of relay K1 will be actuated either up
 or down according to the direction of camera drift. Since relay
 K3 is actuated, +28 volts is suitably applied through actuated
 15 relay K1, manual switches 68 and limit switches 320a and 320b
 to autobalance motor 66, moving the weight 284 in tube 64 to
 compensate for unbalance in the camera 10. The relay K1 can
 be a time delay relay to delay operation of the autobalance until
 steady state condition is reached.

20 The autobalance function is discontinued when I. M. C. is
 commenced. The camera 10 is, however, kept uncaged, of
 course. Relay K4 is energized which breaks the +28 volts
 circuit to the autobalance circuit and removes a short which allows
 the I. M. C. signal to be applied to the pitch torque amplifier 324.
 25 A camera shutter pulse is then applied during the tenth step, and

the operation is completed by the elevator. When the camera is caged and the system generally de-caged, a mount is provided in which a camera is supported by a three axis, low friction torque gimbal in which the center of gravity of the camera is coincident with, or very close to, the pivot point of the gimbal. Controlling means including suitable servos and power supplies are used to operate solenoids suitably attached to the gimbal by means of cables. A captivator or mechanical cager locks the camera in the caged position as required when the camera stabilized mount is not in operation. The captivator releases the camera in operation so that it is free to pivot about the gimbal. The rate gyro senses the angular movement of the mount, and through the servos, a torque solenoid to exert a torque on the mount to oppose the angular movement of the mount. Normal movements are only fractions of a degree. A range of ± 3 degrees, for example, is intended. The gimbal can be capable of movement to ± 15 degrees without difficulty about each axis. The limit to flexure elasticity.

It is, of course, not required that the system command zero angular rate, but a rate signal can be input into the system such that the mount will move to compensate for translation of the aircraft in order to provide for image motion compensation. Similarly, it is not

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51-20

What is claimed is:

- 1 1. A flexure gimbal, comprising: first body adapted to
2 mount a load; a second body; and a pair of second flexures con-
3 necting said first body to said second body, third flexures
4 establishing an axis of rotation for said gimbal.

- 1 2. The invention according to Claim 1, wherein said pair of
2 flexures are small thickness strips positioned adjacently to each other.
3 wise, the strips lying in planes which intersect at right angles.
4 each other.

55-20

1 3. A flexure gimbal, comprising: a first body; a first pair
2 to mount a load; a second body; a first pair of flexures
3 connecting said first body to said second body; said first pair of
4 crossed flexures establishing a first axis of rotation; a third body;
5 gimbal; a third body; and a second pair of flexures connect-
6 ing said second body to said third body; said second pair of
7 crossed flexures establishing a second axis of rotation; and
8 gimbal.

1 4. The invention according to Claim 3, wherein the first pair
2 of flexures are small thickness strips posi- tioned at right angles
3 where, the strips lying in planes which inter- sect at right angles
4 each other.

5-20

1 5. The invention according to Claim 1, wherein said
2 second pair of crossed flexures establishes a second axis of
3 rotation which is orthogonal to the first axis of rotation for said
4 gimbal.

1 6. The invention according to Claim 1, wherein said first pair of
2 flexures, a fourth body; and a third pair of flexures connect
3 said third body to said fourth body, said third pair of flexures
4 establishing a third axis of rotation for said gimbal.

1 7. The invention according to Claim 1, wherein said first pair of
2 flexures establishes three axes of rotation for said gimbal.
3

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1 8. A flexure gimbal, comprising: a first body;
2 to mount a load; a second body; and two pairs of
3 connecting said first body to said second body;
4 crossed flexures mounted in spaced relation
5 of rotation for said gimbal.

1 9. The invention according to Claim 8, wherein
2 pair of flexures are small thickness strips
3 lengthwise, the strips lying in planes which are
4 to each other.

5 -20

1 10. A three axis, flexure supports
 2 a camera or the like, comprising: a cylind
 3 upper body having a central opening and di
 4 dependent side flanges, said upper body be
 5 said camera; a cylindrical middle body hav
 6 channel and a lower diametric channel ori
 7 channel and intersecting partially there with
 8 opening; first two pairs of crossed flexur
 9 dependent side flanges of said upper body,
 10 the upper channel of said middle body, and
 11 of rotation; a channel bar shaped lower bod
 12 center cone; a second two pairs of crossed
 13 respective ends of the lower channel of sai
 14 of said channel bar shaped lower body, and
 15 of rotation; a center support column memb
 16 to fixed structure; and a third two pairs of
 17 tively connecting upper and lower ends of t
 18 to ends of said center support column, and
 19 rotation, whereby said center support colu
 20 upwards through the central opening of sa
 21 upper body to attach with the fixed structure

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1 11. The invention according to claim 11
2 three axes of rotation respectively defined
3 crossed flexures are mutually perpendicular
4 a pivot point for said gimbal.

1 12. The invention constructed and
2 substantially as described with reference to